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LASER INTERFEROMETER TECHNIQUES FOR INSPECTION OF OPTICAL COMPONENTS

September 1975

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Fire Control Development and Engineering Directorate

U.S. ARMY ARMAMENT COMMAND

FRANKFORD ARSENAL

PHILADELPHIA, PENNSYLVANIA 19137

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A method employing laser interferometry was used for detecting inhomogeneities of refraction index in optical glass prior to use in optical fabrication. A Twyman-Green interferometer configuration using a laser source was constructed. System errors were removed by a Moire technique. Samples of A, B, C and D glass were introduced into one of the beams and the resultant fringe patterns analyzed to obtain the magnitude of the index of refraction variations.

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INTRODUCTION

The purpose of this project was to establish a method employing laser interferometry for the detection of inhomogeneities of refraction index in optical glass used to fabricate optical components employed in fire control instruments, e.g., telescopic sights, periscopes, etc. An interferometer configuration, described later in this report, suitable for this purpose was chosen and appropriate modifications made. Several samples of glass were then tested using this procedure.

The conventional method used in striae detection, involved passing a collimated beam from an arc lamp through the sample while it was immersed in a liquid of matched index. When the beam was focused on the observer's pupil, striae parallel to the beam direction became visible as shadowy regions. These patterns were subjectively compared by the observer with standards graded A, B, C and D. Only an imprecise knowledge of glass characteristics could be gained by this subjective technique.

The scheme using laser interferometry was tested to establish a more objective and precise method for acceptance of glass.

THEORY

When a plane monocromatic wavefront is passed twice through an immersed sample of thickness t(x,y), where x and y are coordinates perpendicular to beam directon, it will obtain a phase profile,

$$\Delta\phi(x,y) = \frac{2\ \Delta\eta\ t(x,y)}{\lambda} \tag{1}$$

where $\Delta\eta(x,y)$ is the change in index of refraction of the glass with respect to an arbitrary reference point, $t(x,y)$ is the thickness of the glass, λ is the wavelength of the light and $\Delta\phi(x,y)$ is the relative change in phase of the wavefront in wavelengths. If the thickness varies negligibly, then, from equation 1,

$$\Delta\eta(x,y) = \frac{\lambda\ \Delta\phi(x,y)}{2t} \tag{2}$$

DESCRIPTION OF INTERFEROMETER

The configuration used for measurement of the index change is a Twyman-Green interferometer, which operates as shown in Figure 1. A laser beam of $5145A^{O}$ wavelength is expanded and split by a 50-50 beamsplitter. In one arm of the interferometer, the beam passes twice through the sample and them recombined with the other beam. The sum of

the beams is then sent through a photographic recording of an interferogram made when the sample was absent. This produces a Moire pattern in which system phase errors are removed and this pattern can be analyzed to obtain phase deviation $\Delta\phi$ of equation 2.

The sample is immersed in a fluid of matching index which is stirred constantly to maintain homogeneity.

PROCEDURE

Bromonaphthalene (1.660 refractive index) and Mineral Oil (1.488) are mixed to approximate the index of refraction of the sample according to the formula

$$\frac{V_1}{V_2} = \frac{\eta-\eta_2}{\eta_1-\eta} \tag{3}$$

where V_1 and V_2 are the volumes of the two component liquids of indices η_1 and η_2 respectively, and η is the index of the sample.

Closer matching is accomplished by passing the laser beam along the edge of the immersed sample and onto a viewing screen as in Figure 2. When the indices of sample and fluid are matched, fluid of higher or lower index is added until the deflected portion joins the undeviated portion.

The sample is then removed and the expanded beam allowed to pass through the interferometer. When the mirrors are tilted until the fringes are barely visible, the interferogram is recorded as a photographic transparency which is then kinematically replaced after development. The sample is then replaced and the resultant Moire pattern interpreted to measure phase variations caused by striae.

$\Delta\phi$ of equation 2 was obtained by measuring the deviations of fringes in the interferogram in terms of the number of line pairs. One quarter fringe pair is the least deviation an an interprogram detectable by human observation. By equation 2, the least detectable index variation in the experimental arrangement is

$$\Delta\eta = 6.4 \text{ X } 10^{-6} \text{ cm/t} \tag{4}$$

where t the path through the sample, is in centimeters.

RESULTS

Figure 3 shows two interferograms of a piece of grade A glass. The fringes shows less than .25 fringe deviation which means that since its

thickness was 7 cm, by equation 2, the change in refractive index is less than 9.2 X 10^{-7}.

The interferograms of Figure 4 are of a piece of grade B glass. Proceedings from one side of the sample to the other, the fringes deviate one fringe pair. This represents a change in index of 2.6 X 10^{-6}.

The interferograms of Figure 5 are of piece of grade C glass. The fringes on the left are zero-order and show an irregularity of two fringes equivalent to an index variation of 5.2 X 10^{-6}.

Samples of grade D glass demonstrated sharp discontinuities and large curved deviations ranging from 20 to 30 fringe pairs representing inhomogenities of 1.6 X 10^{-4} to 4.1 X 10^{-5} in amplitude.

CONCLUSIONS

Striae were detectable by passing the beam through the sample parallel to the striae. From grade to grade, index variations showed a difference in their quantitative value and also in their shape. Glass should be able to be graded and selected by accurate measurement of index variations. This method, without automated analysis, should be able to resolve index variations of 6.4 X 10^{-6} divided by the thickness in centimeters. This method provides for a quantitative rather than a qualitative evaluation of glass.

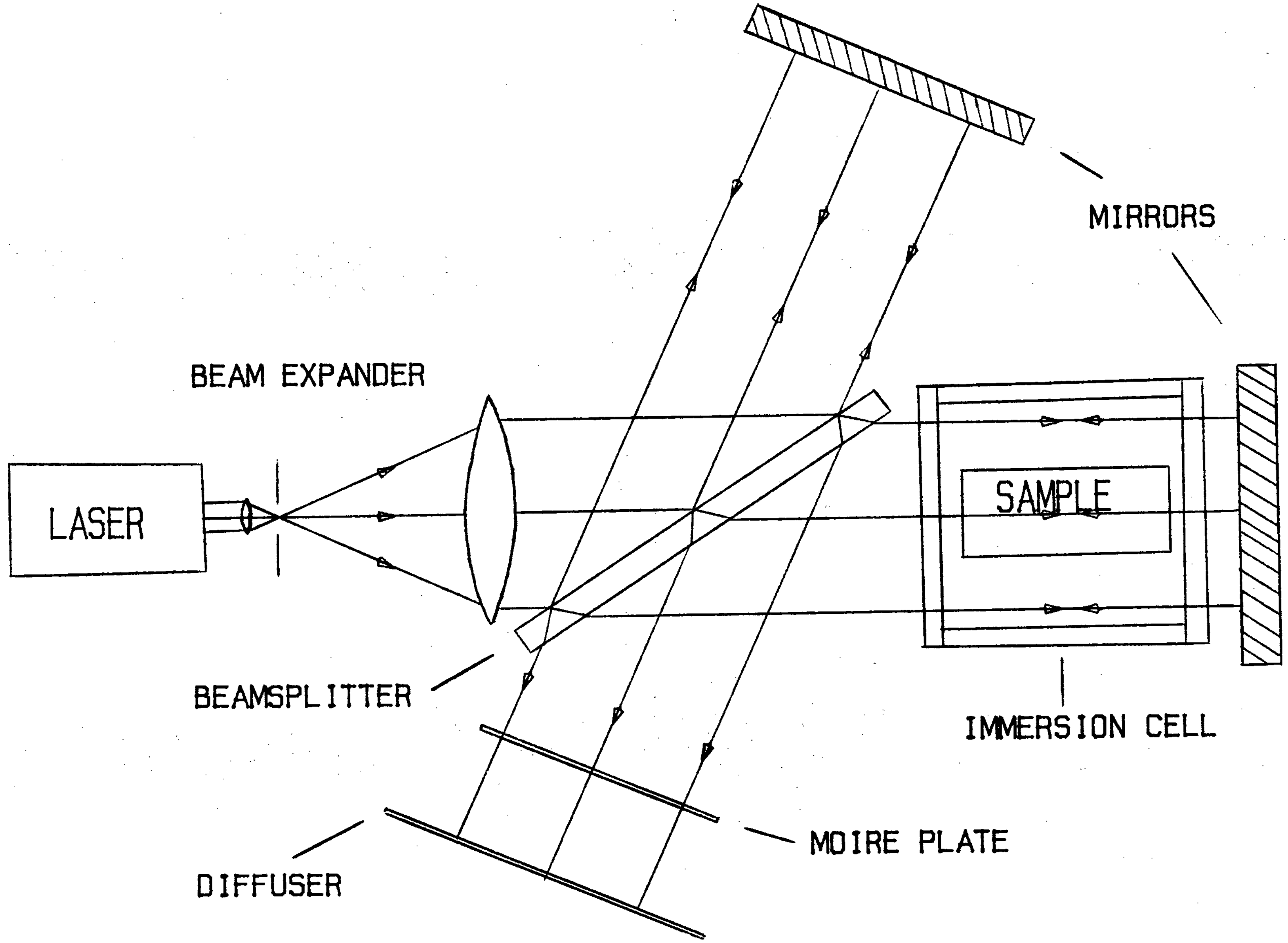

Figure 1 Diagram of Striae Measurement Interferometer

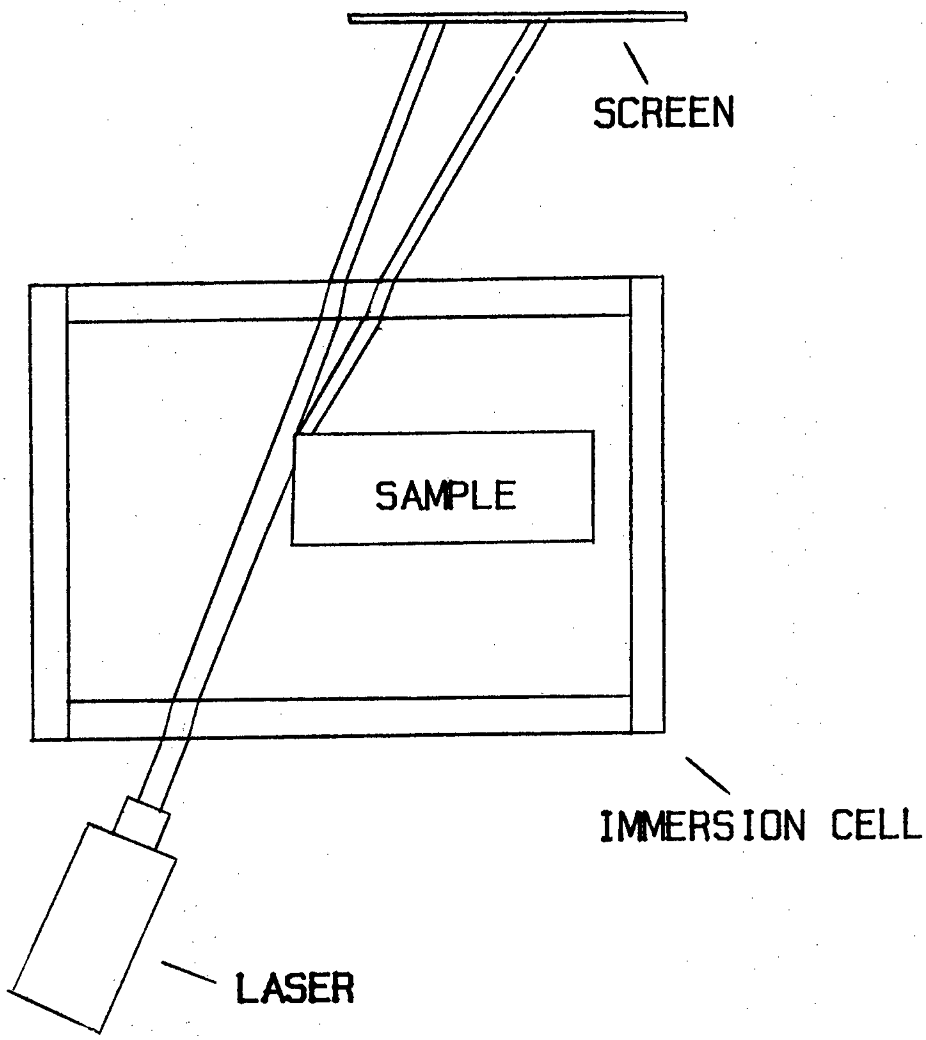

Figure 2. Arrangement for Index Matching

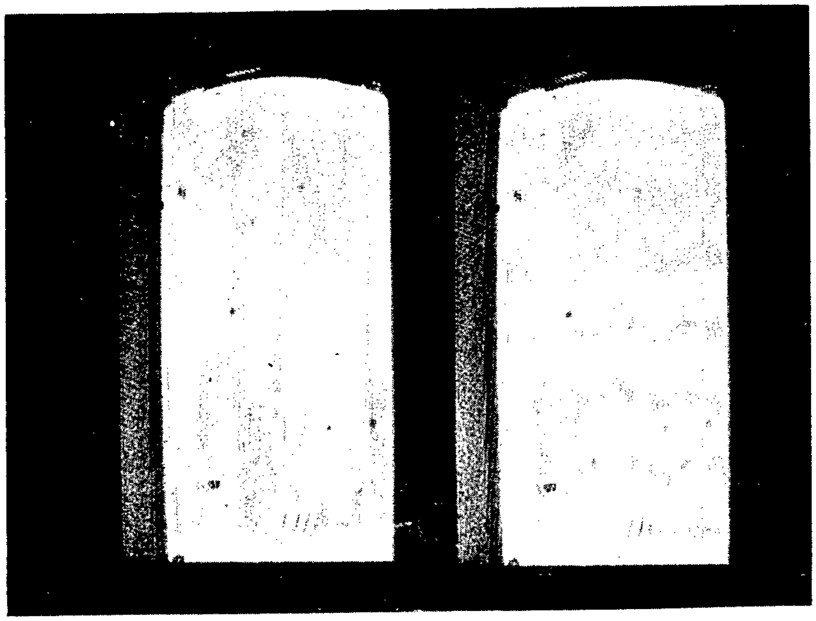

Figure 3. Interferograms for Grade A Sample

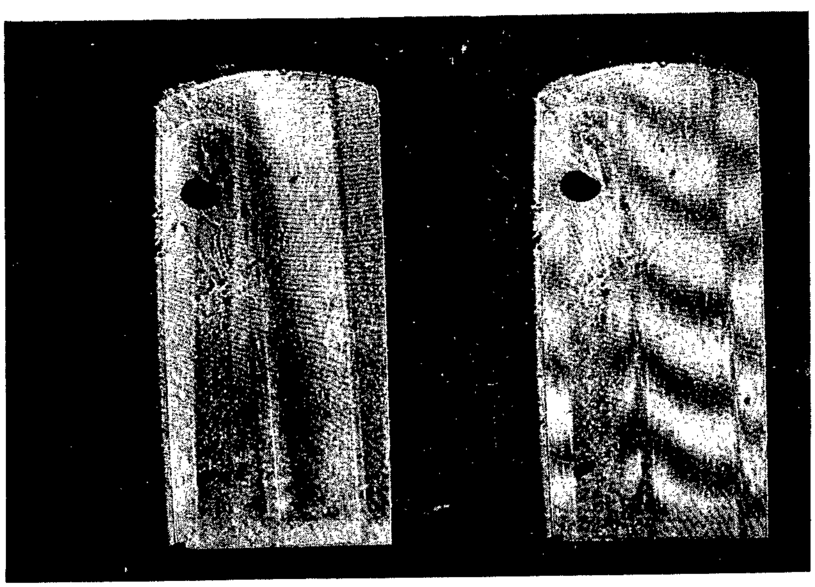

Figure 4. Interferograms for Grade B Sample

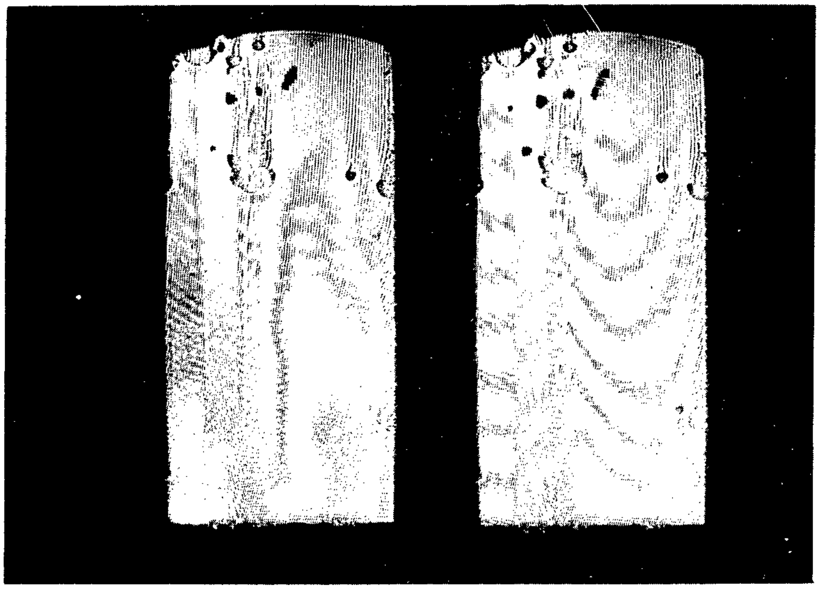

Figure 5. Interferograms for Grade C Sample

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